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Natural Chromaticity of Lattices

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Recently, G. Parzen found that use of the sum $\sum k(s)\beta(s)\delta s$ to evaluate the natural chromaticity of the AGS-Booster gives results that differ from values obtained by measuring the tune at two different values of $\Delta P/P$. Adjusting sextupoles to correct this "incorrect" natural chromaticity results in small tune errors ($\cong 3\times10^{-3}$ at $\Delta P/P = 0.5\%$) that could be significant in tracking studies. Consequently, he now uses a "two-tune" method in ORBIT to evaluate the natural chromaticity. Hence:

$$CH_n = \Delta\nu/\Delta(\Delta P/P) \tag{1}$$

The results he obtains with the summation method and the two-tune method are given below.

	CHX_n	CHY_n
Summation	-5.037	-5.389
Two-Tune	-5.637	-5.440

Table 1. Natural chromaticities of AGS Booster obtained with ORBIT

These results have been checked with PATRICIA. All chromaticity sextupoles were set to zero, and the tunes were determined for several values of $\Delta P/P$. Equation (1) was used to obtain the chromaticity. The results are given in Table 2.

		CHX_n	CHY_n
Summation		-5.093	-5.447
Two-Tune	$\Delta P/P(\%)$	CHX_n	CHY_n
	0.125	-5.635	-5.439
	0.100	-5.637	-5.441
	0.075*	-5.639	-5.443
	0.050*	-5.640	-5.444
	0.025*	-5.640	-5.444
	-0.025*	-5.648	-5.448
	-0.050	-5.648	-5.450
	-0.075	-5.651	-5.452
	-0.100	-5.652	-5.454
	-0.125	-5.654	-5.456

Table 2. Values of natural chromaticity determined with PATRICIA for the AGS-Booster. * denotes value limited by round-off of tunes.

The natural chromaticity obtained by summation with PATRICIA differs from the summation results of ORBIT by 0.06 in both planes. This is thought to result from differences in the step $\delta(s)$ used to sum over the length of a dipole.The value of chromaticity determined by the two-tune method reproduces the two-tune results of ORBIT and varies slowly with $\Delta P/P$. The chromaticity in the vertical plane is essentially unchanged when determined by the summation or two-tune methods, however the horizontal chromaticity differs by 0.5 units between the two methods. This is a difference of 10%!

The two-tune method of determining the natural chromaticity has been applied to the RHIC lattice to see whether or not the 10% discrepancy remains -- this would be of even greater importance in RHIC where that natural chromaticity is approximately ten times higher than it is in the Booster. The results obtained for the RHIC lattice ARH3NEW appear in Table 3.

		CHXn	CHYn
Summation		-56.277	-56.645
Two-Tune	$\Delta P/P$(%)	CHXn	CHYn
	0.02	-56.48	-56.76
	0.01 *	-56.48	-56.71
	0.005*	-56.40	-56.68
	-0.005	-56.38	-56.64
	-0.01	-56.35	-56.62
	-0.02	-56.30	-56.58

Table 3. Comparison of natural chromaticities for the RHIC lattice ARH3NEW obtained with PATRICIA using the summation and two-tune determinations. * Denotes that the value of chromaticity may be limited by the small tune differences at these values of $\Delta P/P$.

The values of natural chromaticity in Table 3 indicate a difference between the two methods of ≅0.1 for the X chromaticity and a difference of ≅0.01 for the Y chromaticity. The 0.1 difference in horizontal chromaticity corresponds to a $\Delta\nu$=0.001 when $\Delta P/P$=1.0%; hence the difference in the two methods isn't important for RHIC. The effect isn't a fixed percentage of the natural chromaticity; it could be related to the bending radius.

The comparison was extended to the SSC, a machine having even larger natural chromaticity and larger bending radius. The results are listed in Table 4.

		CHX	CHYn
Summation		-221.56	-221.57
Two-Tune	ΔP/P(%)	CHXn	CHYn
	0.01	-221.74	-221.74
	0.0075	-221.71	-221.71
	0.0050	-221.68	-221.68
	-0.0050	-221.64	-221.64
	-0.0075	-221.65	-221.64
	-0.01	-221.68	-221.66

Table 4. Comparison of natural chromaticity for an SSC using the summation and two-tune formalism.

In this case the differences between the two methods are small and essentially equal in both planes. It is seen that the difference between the two methods is essentially the same for RHIC and the SSC even though their bending radii differ by a factor of 1:42.